The Evolution of the U.S. Automobile Industry and Detroit as Its Capital

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Abstract

In its first fifteen years the U.S. automobile industry was characterized by a great deal of entry and the number of firms exceeded 200. Despite robust growth in the market for automobiles, the industry subsequently sustained a prolonged shakeout in the number of producers and evolved to be an oligopoly dominated by three firms. The industry also evolved to be heavily concentrated around Detroit, Michigan, which not only was home to its top three firms but most of its other leaders. A model of industry evolution characterized by heterogeneous firm capabilities, increasing returns associated with R&D, and a birth and inheritance process governing entry is developed to explain these patterns. Predictions of the model concerning entry and firm survival are tested using data on the origin and years of production of every entrant into the industry. The shakeout is shown to result from a process imparting strong advantages to early entrants, and the geographic concentration of the industry is attributed to the success of four early entrants around Detroit, who in turn spawned a large number of successful firms in the Detroit area that together dominated the industry.

[Key words: Agglomeration, Spinoffs, First-mover Advantatages]
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Steven Klepper

I. Introduction

Between 1900 and 1930, Detroit experienced nearly unparalleled growth for a large city, growing six-fold from a population of 305,000 to 1,837,000. There was no secret formula behind this growth. It was fueled by the concentration around Detroit of the automobile industry, which by 1929 was the largest industry in the U.S. (Davis [1988, p. ix]). The industry was not initially concentrated around Detroit, with numerous firms entering through the eastern seaboard and the midwest. By 1909, when there were well over 200 producers, Detroit was the leading center of automobile production, but it was in the subsequent era that Detroit rose to preeminence. After 1909 the number of firms in the industry fell sharply and within ten years most of the leading makes of automobiles were produced by Detroit-area firms, with the industry evolving to be an oligopoly dominated by three famous Detroit firms, General Motors, Ford, and Chrysler.

While industries are typically agglomerated geographically, it is rare for industries to be as concentrated around one region as automobiles (Ellison and Glaeser [1997]). Unraveling the causes of the extreme shakeout and concentration of the auto industry around Detroit thus promises to shed light on one of the driving questions of the burgeoning literature on economic geography, namely what forces contribute to the agglomeration of industrial activity. Numerous explanations have been advanced for the concentration of the automobile industry around Detroit. Some emphasize Detroit's low-cost access by water to raw materials and major markets for autos and Detroit's many small machine shops and skilled laborers available to supply the industry (Rae [1980]). Coupled with increasing returns to scale, a reasonable assumption given the oligopolistic structure that emerged in the industry, one has the main ingredients of Krugman et al.'s (Krugman [1991], Futia, Krugman, and Venables [1999]) theory of agglomeration. Other explanations emphasize factors making Detroit's initial entrants especially capable competitors. Coupled with positive externalities associated with knowledge spillovers and more developed input markets (Tsai [1997], Rae [1980]), one has the main ingredients of agglomeration theories featuring externalities and path-dependent processes (Arthur [1988]). Indeed, the auto industry has been a kind of litmus test of competing theories of agglomeration, but no consensus has emerged for the concentration of the industry around Detroit, reflecting deficiencies in all the proferred explanations (Tsai [1997]).

The purpose of this paper is to exploit the wealth of information that has been collected about the industry and the heritage of its producers to gain new insight into the forces that shaped its evolution. Using data on the location and years of production of every manufacturer of automobiles from 1895 to 1966 and on the annual production of the leading firms, the evolution of the market structure and the concentration of the industry around Detroit is traced. Information on the origin of each entrant into the industry is also used to identify the pre-entry experiences of each firm. Three types of firms with distinctive experiences that could be interpreted as the basis for firm "capabilities" are distinguished: preexisting firms diversifying from related industries, new firms founded by people who headed firms in these same related industries, and new firms founded by employees of incumbent automobile firms. The analysis focuses on how the background of firms and the timing of their entry affected their performance, which in turn is used to gain insight into the factors conditioning the evolution of the industry's market structure and geographic distribution of activity.

A version of the model of industry evolution developed in Klepper [1996, 2002a] is used to structure the analysis of the data. It features how heterogeneity in firm capabilities, increasing returns to firm size associated with research and development, and costly firm growth can account for a rise and then shakeout in the number of producers and the evolution of an oligopolistic market structure. A birth and heredity process is added to the model to analyze the entry of new firms started by employees of incumbent firms. It is shown that with this additional component, the model can not only explain the evolution of the industry's market structure but also its concentration around Detroit, Michigan, attributing the latter development to the chance location around Detroit of four of the most successful early entrants into the industry and the many firms they spawned. Numerous distinctive hypotheses are derived from the model that are used to test its explanation for the evolution of the industry's horizontal and geographic market structure.

The paper is organized as follows. The history of the industry is first reviewed in Section II. The model of industry evolution is then presented in Section III. Various predictions are derived from the model concerning entry, firm location, and firm survival in Section IV. Firm entry and survival analyses are used to evaluate the predictions in Section V, and more formal econometric methods are used to test the predictions in Section VI. Implications of the findings are discussed in Section VII..

II. History of the Industry

Smith [1968] compiled a list of every make of automobile produced commercially[1] in the United States from the start of the industry in 1895 through 1966. He lists the firms that manufactured each make, their location, the years they manufactured the make, and any reorganizations and ownership changes the firms underwent. Smith's list of makes was used to derive the annual number of entries, exits, and manufacturers of automobiles for the period 1895-1966, where entry and exit dates are based on the first

[1] Smith [1968, pp. 183-184] confines his list to firms that manufactured and sold to the general public. Other lists, some of which are more inclusive and others less inclusive, generally yield similar entry and exit patterns (Klepper and Simons [1997, pp. 387-388], Klepper [2002b]).

and last year of commercial production of all makes of a producer. These series are graphed in Figure 1.

The number of firms that entered the industry grew steadily from 1895 to 1907, peaking at 82 in 1907. Entry remained high for the next three years and then dropped sharply. It averaged 15 firms per year from 1911 to 1922 and became negligible after 1922, with only 15 firms entering from 1923 through 1966. After the first few years, the industry exit rate exceeded 10% for many years, and by 1910 the number of exits overtook the number of entries. Except for the two-year period 1919-1921, the number of firms fell steadily from 1909 to 1941, dropping from a peak of 272 in 1909 to 9 in 1941.

Not surprisingly given this drastic decline in the number of firms, the industry evolved to be a tight oligopoly dominated by three firms, General Motors, Ford, and Chrysler. General Motors was formed in 1908 as a merger of a number of firms, with its most prominent components, Buick, Cadillac, and Olds Motor Works, dating back respectively to 1903, 1902, and 1901. Ford Motor Company entered in 1903. Chrysler Corporation emerged in 1924 through the efforts of Walter Chrysler, ex-president of Buick, to reorganize two of the leading firms in the industry that had merged after falling on hard times, Maxwell Motor Corporation, which dated back to 1904, and Chalmers Motor Co., which dated back to 1906. In 1911, Ford and General Motors were the top two firms, accounting for 38% of the industry's output. By the 1920s their joint share had increased to over 60%, and after 1930 General Motors, Ford, and Chrysler jointly accounted for over 80% of the industry's output (FTC [1939, p. 20]).

General Motors, Ford, and Chrysler were all based in Detroit, Michigan, which for many years had been the geographic center of the industry. The industry was not, however, originally focused around Detroit. The annual number of firms and the percentage of all firms located in the Detroit area[2] from 1895 to 1941, when the number of firms reached a trough of 9, is presented in the bottom two panels of Figure 2. In the first six years of the industry, 1895-1900, there were 69 entrants. Packard Motor Car Co. (nee Ohio Auto Co.) entered in 1900 and moved to Detroit in 1903, but otherwise no manufacturer was located in Detroit until Old Motor Works in 1901. Subsequently, the num-

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[2] In addition to Detroit, the Detroit area was defined to include the following locations in Michigan, all of which are within approximately 100 miles of Detroit: Adrian, Chelsea, Flint, Jackson, Marysville, Oxford, Plymouth, Pontiac, Port Huron, Sibley, Wayne, and Ypsilanti. The boundaries of this region were chosen to reflect multiple locations of some of the firms within the region. For example, Olds Motor Works operated plants in both Lansing and Detroit and Buick operated plants in Detroit, Flint, and Jackson, suggesting that Lansing, Flint, and Jackson, three of the further cities from Detroit in the defined region, were in the same geographic sphere as Detroit. While most firms located in the Detroit area maintained this location over their entire period of automobile production, 11 firms moved into or out of the Detroit area. In the econometric analysis, the location of these firms was allowed to vary on an annual basis, but in all compilations the 11 firms were assigned a single location based on where they were located for a majority of their years of automobile production.

ber of firms in the Detroit area rose, reaching a peak of 41 in 1913, four years after the peak in the number of firms in the industry. The number of Detroit-area firms subsequently declined along with the decline in the total number of automobile producers. After the entry of Olds Motor Works in 1901, the percentage of firms in the Detroit area rose to 15% by 1905, then fell back some in the next four years after which it increased to 24% by 1916. It subsequently fell back again in the next eight years or so, after which it climbed to over 50% by 1935.

The concentration of activity around Detroit was actually considerably greater than the percentage of firms based in the Detroit area. The editors of the magazine *Automobile Quarterly* compiled a list of the leading makes of American automobiles beginning in 1896 based upon production figures by make (Bailey [1971]). Through 1900 at most six total makes are listed, with 14 or 15 makes listed from 1905 to 1924 and 18 makes listed by 1928, after which nearly all the makes were manufactured by firms based in the Detroit area. The annual number of makes manufactured by Detroit-area firms for 1896 to 1928 is plotted in the top panel of Figure 2. The one make listed for the Detroit area in 1896 and 1897 reflects one experimental car made by Ford and Olds respectively in these two years. The first listing of a Detroit-area firm that produced more than one car was Olds Motor Works in 1901, when it was credited with the manufacture of 425 cars. Olds was the only firm in the Detroit area listed as one of the (nine) industry leaders in 1901. Subsequently, the number of makes manufactured by Detroit-area firms increased through 1915, when it reached 13 (out of 15 makes listed), and then reached 15 (out of 18) by the end of the period in 1928. With the leading makes accounting for well over 80% of the total industry output after 1910, firms in the Detroit area dominated the industry by the mid-1910s. Fourteen separate firms in the Detroit area populated the ranks of the industry leaders in the decade 1911-1920,[3] and Detroit-area firms continued to dominate the industry for the next 45 years.

III. Model of Industry Evolution

Three key ideas are featured to explain the evolution of the market structure and geographic distribution of activity in automobiles. The first is a process of increasing returns that eventually chokes off entry and leads to the evolution of a concentrated market structure. The second is persistent heterogeneity in firms' competitive abilities that originates in the experiences of firms and their founders prior to entry. The third is a birth and heredity process that underlies the agglomeration of the industry around Detroit. The model developed by Klepper [2002a] provides a convenient framework to bring to-

[3] Even these figures understate the dominance of Detroit, with two of the other three prominent non-Detroit firms having links to Detroit. One, Studebaker, entered initially by marketing the cars of a Detroit company, E-M-F, that it later acquired. The other, Nash, was a leading firm acquired by Charles Nash, the ex-president of General Motors, in 1916.

gether these three ideas. It already embodies the first two ideas, and the third idea is grafted onto the model through the specification of the process governing entry.

A. Specification of the Model

The model contains many simplifications and stylizations designed to isolate the role of R&D, where R&D encompasses all efforts devoted by firms to improving their technology. The model is specified in terms of discrete time intervals, where period 1 denotes the start of the industry. In each period, it is assumed that new opportunities for technological improvements arise, and incumbent firms conduct R&D to lower their average cost.[4] Firms are assumed to differ in terms of the productivity of their R&D, and all innovations are assumed to be imitated one period after they are introduced. This is modeled as follows. The average cost of firm i in period t, c_{it}, is

$$c_{it} = c_t - a_i g(r_{it}) + \varepsilon_{it},$$

where c_t is a cost component common to all firms in period t, r_{it} is firm i's spending on R&D in period t, $\varepsilon_{it} \geq 0$ is a random cost shock to firm i in period t, and a_i calibrates the productivity of the firm's R&D efforts. For simplicity, unit transportation costs, which are embodied in c_t, are assumed not to vary across firms or units of output, reflecting the national character of the automobile industry. The reduction in the firm's average cost in period t is determined by the amount of R&D it conducts, r_{it}, and the productivity of its R&D, a_i. The function $g(r_{it})$ is assumed to be such that $g'(r_{it}) > 0$ and $g''(r_{it}) < 0$ for all $r_{it} > 0$ to reflect diminishing returns to R&D. All innovations are assumed to be costlessly imitated after one period, which is modeled as $c_t = c_{t-1} - \max_i\{a_i g(r_{it-1})\}$, where $\max_i\{a_i g(r_{it-1})\}$ is the largest cost decrease from R&D among all firms in period t-1. Last, ε_{it} is a random cost shock that arises from factors such as difficulties in imitating the leading firm's innovations, unanticipated capital shortages, lax management, etc. Cost shocks, which are assumed to be independent across periods, cause the firm's average cost to exceed its minimum possible value.

In each period, firms are assumed to retain their customers from the prior period, but if they want to expand they must incur a cost of growth of $m(\Delta q_{it})$, where Δq_{it} is the growth in the firm's output and $m'(\Delta q_{it}) \geq 0$ and $m''(\Delta q_{it}) \geq 0$ for all $\Delta q_{it} \geq 0$ to reflect increasing marginal costs of growth. This cost of growth applies to entrants as well as incumbents and thus determines their size at entry. For simplicity, it is assumed that the industry demand curve is fixed over time and firms are price takers, with price p_t clearing the market in each period.

Firms in the industry in period t choose r_{it} and Δq_{it} to maximize Π_{it}, their profits in period t before the realization of the cost shock ε_{it}:

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[4] R&D to improve product quality can be thought of as lowering the firm's average cost per unit of quality and thus can be accommodated.

(1) $\Pi_{it} = [p_t - c_t + a_i g(r_{it})] (q_{it-1} + \Delta q_{it}) - r_{it} - m(\Delta q_{it})$.

The decision to exit after the realization of the cost shock is assumed to be based only on the firm's current profitability. If the firm's cost shock is such that $\varepsilon_{it} > p_t - c_t + a_i g(r_{it})$ then the firm would lose money by producing, in which case the firm is assumed to disband its R&D operation and permanently exit the industry. Otherwise, the firm remains in the industry and spends r_{it} on R&D and grows by Δq_{it}.

The model in Klepper [2002a] is extended through a more detailed specification of the entry process. In each period there are a limited number of potential entrants with the requisite R&D productivity to enter the industry. Four types of entrants are distinguished: experienced firms, experienced entrepreneurs, spinoffs, and inexperienced firms. The first group diversify from related industries, the second group are de novo firms founded by heads of firms in related industries, the third group are de novo firms founded by employees of incumbent firms, and the fourth group is a residual category of inexperienced de novo firms composed primarily of firms founded by capitalists and firms founded by lower-level employees in related industries. Let a_{max} denote the maximum R&D productivity of any firm. It is assumed that some experienced firms, experienced entrepreneurs, and spinoffs attain a_{max}, but all the inexperienced firms lack the pre-entry experience needed to attain a_{max}. The inexperienced firms are also assumed to have a less favorable distribution of R&D productivities than the other three types of firms. This is specified as follows. Experienced firms, experienced entrepreneurs, and spinoff potential entrants are assumed to have the same distribution of R&D productivities, denoted as F(a). The distribution of R&D productivities for the inexperienced firms, G(a), is such that $(F(a)-F(p))/(1-F(p)) < (G(a)-G(p))/(1-G(p))$ for all $p \leq a < a_{max,}$ which ensures that for any cutoff p, the truncated distribution of R&D productivity above p for the experienced firms, experienced entrepreneurs, and spinoffs stochastically dominates that of the inexperienced firms.[5] Each firm is assumed to know its R&D productivity at its time of entry, and for now it is assumed that its R&D productivity remains fixed over time.

Potential entrants in each period enter if their maximum possible profits based on (1) (with $q_{it-1} = 0$) are positive. For simplicity, it is assumed that to take advantage of local knowledge and to avoid the costs of moving, entrants locate where they are based, which for de novo firms is where their founder(s) lives. Let EF_t, EE_t, SP_t, and IF_t denote number of potential entrants of experienced firms, experienced entrepreneurs, spinoffs and inexperienced firms in period t. These evolve as follows. At the start of the industry, there are experienced firms and entrepreneurs with sufficiently high R&D productivities

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[5] Letting p=0, this implies F(a)<G(a), which is the standard condition for stochastic dominance. If only R&D productivities above p are considered, the respective truncated distributions are (F(a)-F(p))/(1-F(p)) and (G(a)-G(p))/(1-G(p)), so the assumed condition is the analogous condition for stochastic dominance for the truncated distributions.

to enter profitably. As these firms enter, their ranks get depleted, causing EF_t and EE_t to decline over time. Spinoffs are assumed to be governed by a birth and heredity process. Employees of incumbent firms are assumed to learn from their experiences, which they can exploit in their own firms. Only employees with the requisite organizational skills, knowledge, and risk preferences start spinoffs. It is assumed that better-performing firms have superior learning environments, which leads them to spawn more spinoffs and spinoffs with higher R&D productivity. Furthermore, as the industry expands, employment rises, which is assumed to increase the number of potential spinoff entrants, causing SP_t to rise. The last category of inexperienced firms is composed primarily of two types of firms. One type is founded by capitalists, who typically hire experienced employees of incumbents to direct their firms. It is assumed that the number of these potential entrants increases in proportion to the number of employees in the industry, comparable to potential spinoff entrants. The other type of inexperienced firm is founded by lower-level employees in related industries. Comparable to the first two types of potential entrants, their number is assumed to decline over time as the ranks of employees in related industries willing and able to start their own firms gets depleted over time. Based on the time trends in these two types of potential entrants, the number of potential inexperienced entrants will grow less over time than the number of potential spinoffs, causing IF_t/SP_t to fall over time, and grow faster than the number of potential experienced firm and experienced entrepreneur entrants, causing IF_t/EF_t and IF_t/EE_t to rise over time.

B. Evolution of Market Structure

Klepper [2002a] derives a number of results that apply directly to the proposed model. In each period, larger firms invest more in R&D since the total profit from R&D, which equals the reduction in average cost times the firm's output, is scaled by the firm's output. Furthermore, in every period firms expand until the marginal cost of growth equals their profit per unit of output. The firm's profit per unit of output is determined by its investment in R&D and its R&D productivity. Therefore, larger firms and firms with greater R&D productivity have greater profit margins and thus expand faster. Consequently, among firms that entered in the same period, firms with greater R&D productivity conduct more R&D and are always larger and more profitable than firms with lower R&D productivity. Furthermore, among firms with the same R&D productivity, firms that entered earlier start growing earlier and are thus always larger and more profitable than later entrants.

Expansion of incumbents and (initially) entry is assumed to cause the total output of the industry to rise over time and the average price-cost margin, $p_t - c_t$, of firms that do no R&D to decline over time. When $p_t - c_t$ is high initially, the minimum R&D productivity required for entry to be profitable is low and a range of firms in terms of their R&D productivities enter. As $p_t - c_t$ falls over time, the minimum a_i needed for entry to be profitable rises, causing the percentage of potential entrants of each type that enter the industry to decline over time. Eventually entry becomes unprofitable even for firms with the greatest R&D productivity, at which point entry ceases altogether.

The decline in $p_t - c_t$ also causes the profits of incumbents to decline over time. This is partially offset by the rise in firm R&D over time that occurs as firms grow, which lowers firm average costs. In every period, incumbents that experience a sufficiently large cost shock exit. Incumbents also exit when $p_t - c_t$ falls sufficiently that they cannot earn positive profits even if they produce at their minimum possible cost. The latest entrants with the lowest R&D productivity are always the least profitable and thus the most vulnerable to exit. Thus, even after entry ceases, firms exit, with the latest entrants with the lowest R&D productivity expected to exit first. This causes the number of firms to decline steadily over time, resulting in a shakeout. It also causes the earliest entrants with the greatest R&D productivity to take over an increasing share of the industry's output, which contributes to the evolution of an oligopolistic market structure.

Thus, over time profit margins decline, entry eventually ceases and a shakeout occurs, and the industry evolves to be an oligopoly. The market structure predictions of the model correspond to what occurred in the auto industry. Furthermore, the rates of return on investment of the leading firms, which began at extremely high levels, also declined over time (Epstein [1928, p. 256]). Thus, the model passes an initial hurdle of being able to account for the way the market structure of the automobile industry and the profitability of the firms evolved over time. It remains to be shown that the model can also account for the increasing concentration of the industry in one region, around Detroiit, Michigan. This is shown in the next section, where further predictions are derived from the model that are used subsequently to test its account of the evolution of the automobile industry.

IV. Further Predictions

The model has a number of additional implications concerning firm survival, entry, and the geographic distribution of activity that are reviewed in this section. The predictions regarding entry and regional activity follow straightforwardly from the model. The survival predictions are based on comparable predictions established in Klepper [2002a].

A. Firm Survival

The survival rates of firms will be examined empirically based on their time of entry and background. Regarding the time of entry, the model implies that earlier entry is advantageous. All else equal, earlier entrants have lower hazards at every age than later entrants. But later entrants have lower average R&D productivities, which counteracts the lower hazard of earlier entrants due to the advantage of early entry. As Klepper [2002a] demonstrates, over time the lowest R&D productivity firms disproportionately exit, and at older ages the earlier entrants must have lower hazards, but this may not hold at young ages. This is listed as hypothesis 1 in Table 1 and is illustrated in the cohort survival graph in the top panel of Figure 3. Anticipating the empirical analysis, three cohort survival curves are illustrated, where cohort 1 is the earliest group of entrants, followed by cohorts 2 and 3. Each curve represents the log of the percentage of firms in the entry cohort surviving to each age, so the negative of the slope of a curve is the cohort's hazard rate. The figure is (arbitrarily) constructed so the third cohort has a constant hazard up to its extinction and the other two have the same hazard as the third until older ages, where the survival curves diverge according to time of entry.[6]

The model also has distinctive implications regarding how survival rates differ across firms with different backgrounds. Among contemporaneous entrants, those with higher R&D productivity have lower hazards. The assumptions about the distribution of R&D productivities among the four groups of entrants imply that the inexperienced firms always have lower average R&D productivites and hence higher hazards at every age. This is listed as hypothesis 2 in Table 1 and is illustrated in the bottom panel of Figure 3 for inexperienced and experienced firms for the arbitrary case of constant hazards.[7] It would also be expected that within each of the three more experienced types of entrants, the experienced firms and experienced entrepreneurs from industries more closely related to autos and the spinoffs from better performing parents would have lower hazards at every age than their less advantaged counterparts that entered at the same time. This is summarized as hypothesis 3 in Table 1.

B. Entry

The model has a number of implications regarding entry that go beyond Klepper [2002a]. Let a_t denote the minimum R&D productivity needed for a firm to enter profitably in period t. Over time, a_t rises, which causes the fraction of potential entrants of each type that enter to fall. The number of entrants in period t of the four types of firms is $(1-F(a_t))EF_t$, $(1-F(a_t))EE_t$, $(1-F(a_t))SP_t$, and $(1-G(a_t))IF_t$. Given the assumption that EF_t and EE_t fall over time and SP_t rises over time, it follows that the ratio of spinoff entrants to the sum of experienced firm and experienced entrepreneur entrants, $(1-F(a_t))SP_t/[(1-F(a_t))EF_t + (1-F(a_t))EE_t] = SP_t/[EF_t + EE_t]$, must rise over time. Regarding the inexperienced firms, $1-F(a_t) > 1-G(a_t)$ and as a_t rises over time, $G(a_t)$ will equal 1 before $F(a_t)$, so the number of inexperienced entrants will go to zero before the other three types of en-

[6] These patterns are distinctive. Many theories attribute shakeouts to a particular event, such as an innovation or an information cascade (Utterback and Suárez [1993], Jovanovic and MacDonald [1994], Horvath, Schivardi, and Woywode [2001]). Such theories imply that early entrants have a lower hazard at young but not older ages (Klepper and Simons [2001]), which is the opposite of the illustrated pattern.

[7] Hypothesis 2 is also distinctive. Many theories can accommodate inexperienced firms having higher hazards than experienced firms at young ages, but their logic generally implies that such differences decline with age (Klepper [2002a]) .It was assumed that firm R&D productivities do not change over time, but this is not necessary for hypothesis 2. If firm R&D productivities revert toward a common value as firms age, then at any given age firms that entered with a greater R&D productivity would still be larger. Therefore, they would conduct more R&D and hence have greater profit margins and lower hazards than firms that entered at the same time with lower R&D productivities, and hypothesis 2 would continue to hold.

trants. Therefore, $[EF_t + EE_t]/IF_t$ and SP_t/IF_t may decline initially, but as the industry evolves they must eventually rise. It was assumed that the R&D productivity of spinoff entrants was related to the performance of their parents. Consequently, with the minimum R&D productivity required for profitable entry rising over time, the model implies that the performance of the parents of spinoff entrants should improve over time. At any point in time, the model also implies (by assumption) that better-performing firms will spawn more spinoffs. These predictions are summarized as hypotheses 4a-4d in Table 1.[8]

C. Regional Activity

The model implies that early entrants will be disproportionately experienced firms and experienced entrepreneurs. If the Detroit area attracted few early entrants, then the percentage of entrants accounted for by experienced firms and entrepreneurs should be lower in the Detroit area than elsewhere. Since the inexperienced firms are not expected to be as successful as the spinoff entrants, it would then have to be the spinoff entrants that fueled the growing concentration of activity in the Detroit area if the model is to explain this pattern. This could occur if the earliest entrants in the Detroit area were unusually successful. According to the model, better-performing firms will have more and better spinoffs, and spinoffs will generally locate close to their parents. Hence if the earliest entrants in the Detroit area were unusually successful, this could start a cascading spinoff process in the Detroit area contributing to a growing concentration of the industry around Detroit.

This explanation is dependent on a number of assumptions and has a number of testable implications. First, if spinoffs locate close to their parents, then spinoffs of Detroit-area firms should generally have located in the Detroit area and spinoffs located in the Detroit area should generally have had parents located in the Detroit area. Second, if a few unusually successful early entrants fueled a cascading spinoff process, then the percentage of entrants that were spinoffs should have been higher in the Detroit area than elsewhere. Third, if better-performing firms spawn better-performing spinoffs, then the parents of Detroit-area spinoffs should have performed better than the parents of spinoffs elsewhere. Fourth, if a few unusually successful early entrants in the Detroit area spawned a cascading spinoff process, then it should be possible to directly and indirectly trace back many of the spinoffs in the Detroit area to a few very successful early entrants. Fifth, relatedly the spinoffs in the Detroit area should have had lower hazards of exit at every age than the spinoffs elsewhere. Sixth, the model assumes that better-performing

[8] Hypotheses 4b and 4c concerning the eventual relative decline in the number of inexperienced entrants and the improvement in the performance of the parents of spinoff entrants are distinctive; they follow only if potential entrants know their R&D productivity prior to entry, whereas many theories assume that entrants can learn about their capabilities only by entering (e.g., Jovanovic [1982], Horvath et al. [2001]).

firms spawn better-performing spinoffs because the founders of the spinoffs learn from their parents. Learning is assumed to occur only between a firm and its spinoffs, and no benefits are assumed to accrue to any other firms. Moreover, there are no other mechanisms hypothesized in the model that would allow firms to learn from or benefit from other firms. Therefore, inexperienced entrants that located in the Detroit area would not share in any of the benefits experienced by the spinoffs because of the absence of any kind of agglomeration economy in the model. This implies that in contrast to the spinoff entrants, inexperienced entrants located in the Detroit area should not have had lower hazards than inexperienced entrants located elsewhere. These predictions are summarized as hypotheses 5a-5f in Table 1.

V. General Patterns

To test the various predictions, the firms are divided according to their time of entry and prior experience. To probe the importance of time of entry, firms are grouped into three entry cohorts. Each cohort is constrained to span at least five years, and the cohorts are defined to have comparable numbers of firms. The first cohort contains the 219 firms that entered from 1895 to 1904, the second cohort includes the 271 firms that entered between 1905 and 1909, and the third cohort contains the remaining 235 firms that entered between 1910 and 1966. Firms that were reorganized or acquired by nonautomobile producers were treated as continuing producers. Mergers and acquistions were treated as continuations of the firm whose name was retained, or in the case of mergers the largest firm involved, with the other firms treated as censored exits.[9] Approximately 6% of the firms exited by being acquired by another automobile firm or through a merger.

The classification of firms according to their prior experience is based primarily on Smith [1968] and the brief histories of the firms in the *Standard Catalog of American Automobiles* (Kimes [1996], Gunnell [1992]),[10] which contains an entry for every make of automobile on Smith's list.[11] Smith categorized firms according to whether they entered automobiles from another business. Those that did were classified in the category

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[9] These standards were generally straightforward to implement. The principal exception concerned Chrysler Corporation. Chrysler evolved out of Maxwell Motor Co. and Chalmers Motor Co. when Walter Chrysler, formerly the president of Buick, was called in to reorganize Maxwell, which had recently merged with Chalmers. Maxwell was descended from Maxwell-Briscoe, which was a very successful 1904 entrant that was the centerpiece of the unsuccessful 1910 United States Motor Co. merger organized by one of the founders of Maxwell-Briscoe. Maxwell emerged from the ruins of United States Motor Co., regaining a leading position in the industry until it floundered before Walter Chrysler was brought in to reorganize it. Accordingly, Chrysler Corporation was treated as the lineal descendant of Maxwell-Briscoe.

[10] Due to incompleteness in the historical record of a number of the firms, judgments were also required to classify the firms. These are discussed in Klepper [2002b].

[11] Also consulted were the compilations of Detroit firms in Szudarek [1996] and world-wide producers in Baldwin et al. [1987] and the histories of Ransom Olds' automobile ventures (May [1977]) and the Franklin Automobile Company (Powell [1999]).

of experienced firms. Twenty-five additional firms on Smith's list were identified from the *Standard Catalog* as entering from another business, most often from carriages/wagons. These firms were also classified as experienced firms,[12] yielding a total of 120 experienced firms. Firms were classified into the category of experienced entrepreneurs if in the *Standard Catalog* at least one of their founders was identified as the head of a named firm that was active or had recently been sold. This yielded a total of 108 experienced entrepreneurs. The *Standard Catalog* was used to identify the main prior product produced by each experienced firm and experienced enterpreneur. Firms were classified as spinoffs if at least one of their founders had worked for and/or founded an automobile firm in Smith's list, yielding a total of 145 spinoffs. The latest firm worked for by the founder was designated as the parent of the spinoff and prior firms worked for by the founder were designated as secondary parents.[13] In about 30% of the spinoffs, the motivation for the spinoff could be discerned from the firm's description in the *Standard Catalog* and the circumstances of the firm's founding, and this was recorded. The 352 firms that were not classified as experienced firms, experienced entrepreneurs, or spinoffs were included in the residual category of inexperienced firms.

The first hypothesis in Table 1 deals with how time of entry affects firm survival. It is tested using the survival graphs in Figure 4, which plot the natural log of the percentage of survivors in each cohort versus the age of the cohort. Cohort 1 refers to the 1895-1904 entrants, cohort 2 to the 1905-1909 entrants, and cohort 3 to the 1910-1966 entrants. The top graph includes all the firms and the other four graphs look separately at the four categories of entrants. A curve drops to the horizontal axis at a particular age when the survival rate of the cohort at that age is less than or equal to 1%.[14] The three survival curves for all the firms in the top panel initially overlap until approximately age seven, when they diverge, with cohort 1 having the highest survival rate at older ages, followed by cohort 2 and then cohort 3. Correspondingly, the survival curve of the third cohort drops to the horizontal axis at the earliest age, followed by the second cohort, with the first cohort having well over a 1% survival rate through 1966. With the exception of the intertwining of the survival curves of the last two cohorts of experienced firm entrants, the graphs for each type of entrant are similar. They conform with hypothesis 1 and the predicted patterns in the top panel of Figure 3.

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[12] Only firms that produced automobiles and earlier products under (exactly) the same name were included in this category.

[13] In most cases, only one firm was mentioned for spinoff founders. In some spinoffs there were multiple founders that had worked for different automobile firms. In these cases, the parent of the spinoff was determined based on the founder(s) that were described as the most instrumental in the spinoff, with the prior employers of the other founders classified as secondary parents.

[14] If the last firm in a cohort exited by being acquired and the survival rate to that age exceeded 1%, the cohort survival graph ends at the age of the acquired firm but does not drop to the horizontal axis.

Figure 5 compares the natural log of the percentage survival rates of the inexperienced firms with each of the other three categories of entrants. Only the first two cohorts of each group of entrants are graphed to keep the graphs uncluttered (the patterns are similar for the third cohort as well). The graph in the upper panel compares the inexperienced firms and the experienced firms. The survival curves of the experienced and inexperienced firms in the first cohort of entrants diverge from the youngest ages and their slopes do not change greatly with age, indicating that the difference in their hazards persists with age. A similar pattern holds for the experienced and inexperienced firms that entered in the second cohort. The other two graphs pertaining to the experienced entrepreneurs and spinoffs are similar. The curves overlap more at the youngest ages, but at older ages the experienced entrepreneurs and spinoffs have considerably higher survival rates than the inexperienced firms in the same entry cohort. The curves for the inexperienced firms also tend to have steeper slopes at the older ages, indicating that the hazards of the inexperienced firms remain higher than the other two groups at older ages. This conforms with hypothesis 2 in Table 1 and the predicted patterns in the bottom panel of Figure 3.

Hypothesis 3 pertains to how the particular backgrounds of the experienced firms, experienced entrepreneurs, and spinoffs affect their survival rates. Further breakdowns of the survival curves for these groups according to their backgrounds would result in some very small samples, making comparisons difficult. The analysis of the role of the backgrounds of these firms is deferred until the econometric analysis, where a parsimonious specification can be used to cope with the small samples.

The next set of predictions in hypotheses 4a-4c concerning the composition of entrants is evaluated using Table 2, which breaks down the entrants in each cohort by background. Table 2 also reports various ratios regarding the number of entrants of each type, with experienced firms and experienced entrepreneurs combined into one category due to their similar entry patterns over time. Regarding hypothesis 4a, the ratio of spinoffs to the sum of experienced firms and experienced entrepreneurs rises over the three entry cohorts, as predicted. Regarding hypothesis 4b, the ratio of spinoffs to inexperienced firms rises over the three entry cohorts while the ratio of the sum of experienced firms and experienced entrepreneurs to inexperienced firms falls from cohort 1 to cohort 2 and then rises to cohort 3. Thus, consistent with hypothesis 4b, eventually both ratios rise. To test hypothesis 4c regarding the performance of the parents of spinoff entrants, the total years of production of parents was used as a measure of their performance. Parents were crudely divided according to whether they produced for ten years or more, with parents that were acquired within ten years of entry excluded from the comparison. The percentage of parents that produced ten or more years was 50% (5 of 10) for the parents of spinoffs in cohort 1, 37% (13 of 35) for the parents of spinoffs in cohort 2, and 62% (46 of 75) for the parents of spinoffs in cohort 3. Although the percentage of parents that produced for ten or more years initially dropped from cohort 1 to cohort 2, there were not many spinoffs in the first entry cohort. Once entry became more difficult after 1909, though, the percentage of parents that produced for ten or more years increased markedly and was higher in cohort 3 than in either of the two earlier entry cohorts, consistent with hypothesis 4c. Hypothesis 4d concerning the incidence of spinoffs across firms is tested econometrically in the next section.

The last set of predictions in hypothesis 5 pertain to the concentration of the industry around Detroit. Hypothesis 5a concerns whether the spinoffs that located in the Detroit area had parents in the Detroit area and whether the parents in the Detroit area had spinoffs that located in the Detroit area. Fifty-four spinoffs located initially in the Detroit area, and 50 of them had parents located in the Detroit area. Eleven spinoffs with parents in the Detroit area located elsewhere, so 50 of the 61 spinoffs with parents in the Detroit area located there.[15] Thus, spinoffs with parents in the Detroit area did not locate far from their parents, and few spinoffs without parents in the Detroit area located there, as conjectured.[16]

Hypothesis 5b predicts there would be a disproportionate number of spinoffs in the Detroit area. In total, 15% of the entrants located in the Detroit area. The Detroit area was actually underrepresented in terms of experienced firms, experienced entrepreneurs, and inexperienced firms. Only 9% of the experienced firms and experienced entrepreneurs and 11% of the inexperienced firms located in the Detroit area. What distinguished the Detroit area was spinoffs, with 37% of all spinoffs entering in the Detroit area. More spinoffs entered in the Detroit area than any other type of entrant, accounting for 48% of the firms located in the Detroit area versus only 15% of the firms located elsewhere. Thus, apart from the spinoffs, the Detroit area did not attract a large number of entrants into the industry.

Hypothesis 5c predicts that spinoffs in the Detroit area had better-performing parents than spinoffs elsewhere. Parents were again compared according to whether they produced for ten or more years. Among parents that were not acquired within ten years of entry, the percentage of parents that produced ten or more years was 66% (25 of 38) for the parents of the Detroit-area spinoffs and 48% (39 of 82) for the parents of the spinoffs elsewhere. Thus, consistent with hypothesis 5c, the spinoffs in the Detroit area came from longer-lived parents.

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[15] One of the 11 spinoffs that did not initially locate in the Detroit area moved there soon after its founding, and two of the others were founded in their home cities by sales agents based outside of the Detroit area.

[16] The other 80 spinoffs (which did not have parents in the Detroit area and located outside of the Detroit area) also tended to locate close to their parents. Sixty of them, or 75%, located within a 100 miles of where they were working. Some of the other 20 involved founders who had already left their employers before starting their own firms and seemingly had moved on to other locations. This may have been more

Hypothesis 5d predicts that it should be possible to trace a large number of spinoffs in the Detroit area to a few very successful early entrants in the Detroit area. This is evaluated using Table 3, which identifies the five firms with the most spinoffs and reports information about the firms and their spinoffs. The first four firms, Olds, Buick/General Motors, Cadillac, and Ford, were all early entrants that located in the Detroit area. The fifth firm, Maxwell-Briscoe, which was a spinoff descended from Olds, did not initially enter in the Detroit area but moved there later, where it spawned all but one of its spinoffs. Olds, Buick, Cadillac, and Ford quickly reached the ranks of the production leaders of the industry, attaining the number one or two rank within five years of entry. Given the paucity of experienced firms and experienced entrepreneurs, the Detroit area was an extremely unlikely place for the entry of four such successful firms. But they were led by extremely able men, three of whom had headed engine and carriage firms in the Detroit area before the industry began in 1895. The four firms collectively spawned 22 spinoffs, and 19 additional firms descended from these 22 spinoffs, for a total of 41 descendants. Their descendants were extremely successful, accounting for all but two of the subsequent twelve entrants in the Detroit area that made it into the ranks of the production leaders. Their descendants also played an important role, as acquisitions, in the success of General Motors, Ford, and Chrysler.[17] Even the three principal industry leaders outside the Detroit area were influenced by employees of the four firms.[18] Thus, not only were most of the leading firms in the Detroit area descended from Olds, Buick/General Motors, Cadillac, and Ford, but in one way or another employees of the four firms influenced nearly all the leading firms in the industry.

The remaining two parts of hypothesis 5, parts e and f, pertain to the survival experiences of spinoffs and inexperienced firms in the Detroit area versus elsewhere. These hypotheses are evaluated using the survival graphs in Figure 6. The top two graphs present the survival curves for the three cohorts of spinoff entrants in the Detroit area and elsewhere. They further establish the extraordinary performance of the Detroit spinoffs, particularly the first two cohorts of spinoff entrants in the Detroit area. These firms had

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prevalent among the spinoffs not connected to the Detroit area, perhaps reflecting the lesser success of their parents relative to those of spinoffs connected to the Detroit area, as discussed below.

[17] General Motors acquired Chevrolet, itself a spinoff from General Motors, which it used to displace Ford as the industry leader. Ford acquired Lincoln, another General Motors spinoff, which provided it with a high quality line. Three of the descendants, Maxwell-Briscoe (in the form of its successor, Maxwell Motors), Chalmers, and Dodge, formed the core of Chrysler.

[18] The three main industry leaders outside the Detroit area were Studebaker, Nash Motors Co., and Willys-Overland Co. Studebaker was a leading carriage producer. It rose to prominence in the automobile industry by acquiring E-M-F, a Detroit firm that was descended from an Olds spinoff and was cofounded by two prior employees of Ford and Cadillac. Charles Nash, the head of Nash Motors, was the president of General Motors before acquiring Thomas B. Jeffrey & Co., the producer of the Rambler, and changing its name to Nash Motors. Willys-Overland was reorganized by Walter Chrysler, who had headed Buick and later organized the Chrysler Corporation.

much higher survival rates to older ages than spinoffs outside the Detroit area. The other two survival graphs in Figure 6 pertain to the inexperienced entrants in the Detroit area and elsewhere. These patterns are quite different. The cohort survival curves for the Detroit-area inexperienced firms resemble those of the inexperienced firms outside the Detroit area at young ages, but they all end by 10 years of age, reflecting that no Detroit-area inexperienced firm survived over 10 years (one was acquired at age 10). In contrast, a nonnegligible percentage of inexperienced firms that located outside of the Detroit area survived over 10 years.

The failure of the Detroit-area inexperienced firms to survive to older ages suggests that at some point the Detroit area may have become a difficult place for the inexperienced firms, and possibly all firms, to compete. Indeed, after 1916 entry rates in the Detroit area fell off sharply. Prior to 1916 the percentage of entrants that located in the Detroit area had been steadily rising, increasing from 10% in 1895-1904 to 14% in 1905-1909 and 29% in 1910-1916, but after 1916 it was only 12%. While the entry of all four types of firms declined, the decline was particularly severe for the inexperienced firms. In 1910 to 1916, the Detroit area attracted 19% of the inexperienced entrants, but after 1916 it attracted only 1 of 28, or 4%, of the inexperienced entrants. All this suggests that the success of the Detroit-area firms was mainly attributable to their pedigree and not their location, which may actually have been disadvantageous as competition in the industry intensified.

VI. Econometric Analysis

The various hypotheses can be tested using econometric methods, which facilitates a more detailed investigation and allows for the relevant factors to be analyzed together. The hypotheses concerning firm hazards are tested first, followed by tests of the hypotheses concerning firm spinoff rates.

A. Firm Hazards

The hypotheses about firm hazard rates are tested using the following specification. The hazard of firm exit at age t, h(t), is modeled according to the Gompertz specification:

$$h(t) = \exp\{(\alpha_0+\underline{\alpha}'\underline{x})t\}\exp\{\beta_0 + \underline{\beta}'\underline{z}\},$$

where $\underline{x}$ and $\underline{z}$ are vectors of covariates and the other terms are coefficients. The first exponential term allows the age of firms to affect (monotonically) their hazard rates. It also allows for the variables in $\underline{x}$ to condition how age affects the hazard. In particular, the theory predicts that firm hazard rates may not be ordered by time of entry at young ages but will be ordered by time of entry at older ages, which implies that time of entry should condition the effect of age on the hazard. The second exponential term allows the variables in $\underline{z}$ to affect the hazard proportionally at all ages. Included in $\underline{z}$ are the firm background variables that distinguish the experienced firms, experienced entrepreneurs, and spinoffs from the inexperienced firms. Also included in z are variables pertaining to whether firms were located in the Detroit area.

A series of models that control for successively more factors are estimated. Model 1 includes in the vector z dummies equal to 1 for experienced firms, experienced entrepreneurs, and spinoffs. Separate dummies equal to 1 are also included for experienced firms and experienced entrepreneurs with backgrounds in the carriage and wagon, bicycle, and engine industries, which are the industries most closely related to automobiles. A dummy equal to 1 for Detroit-area firms and dummies equal to 1 for entrants in cohorts 1 and 2 are also included in z, with the cohort entry dummies also included in the vector x.

The estimates of this model are presented in the first column of Table 4, with standard errors in parentheses and significance levels based on one-tailed tests. The coefficient estimates of the dummies for the three types of experienced firms are all negative, sizable, and significant, consistent with the graphs in Figure 5. The coefficient estimates for the dummies for experienced firms and experienced entrepreneurs from the related industries of carriages and wagons, bicycles, and engines are also negative, with the former also significant, consistent with more closely related experience lowering the hazard. The coefficient estimates of C1*t and C2*t are both negative and significant while those of C1 and C2 in the proportional term are small and insignificant. As predicted, this implies that at young ages different entry cohorts have similar hazards, but the hazards of the cohorts diverge with age according to the time of entry. The estimates imply that at age 15 the annual hazards of the first two cohorts of entrants are respectively 76% and 48% lower than the third cohort, with these percentages rising to 90% and 67% at age 25. Last, the coefficient estimate for the Detroit-area dummy is negative and significant, implying a 25% lower annual hazard for firms in the Detroit area.

The theoretical model predicted that the superior performance of the Detroit-area firms should be confined to the spinoffs in the Detroit area. To test this, a dummy equal to 1 for spinoffs located in the Detroit area was added to Model 1. The coefficient estimate of this variable in Model 2 is negative and significant, as predicted. More important, the coefficient estimate of the Detroit-area dummy is trivial and insignificant, suggesting that the lower hazard of Detroit-area firms was in fact confined to the spinoffs in the Detroit area. Accordingly, the Detroit-area dummy was omitted from subsequent specifications.

The theoretical model further predicted that the superior performance of the Detroit-area spinoffs should be due to their superior heritage rather than to being located in the Detroit area. This is tested in Model 3 by including variables measuring the performance of the parents of the spinoffs. The only variable that could be constructed for the performance of all the parents is the total number of years they produced autos, and this was added to Model 2. To probe how the performance of the spinoffs was affected by conditions in their parents during the tenure of the spinoffs' founders, three dummy variables were created. The first equals 1 for spinoffs whose parent was ranked among the production leaders in the year of the spinoff or the preceding five years. The second equals 1 for spinoffs whose parent was the number one producer in the industry in the year of the spinoff or the preceding five years. The third equals 1 for spinoffs whose secondary parent (i.e., the firm the spinoff's founder worked for immediately before the parent of the spinoff if the founder had worked for at least two auto firms) was the number one producer in the industry in the year of the spinoff or the preceding five years. The first dummy added little explanatory power to Model 2 due to its high correlation with the years of production of the parent, but the other two dummies had greater explanatory power and were included as covariates in $\underline{z}$.[19] Also included in $\underline{z}$ is a dummy equal to 1 for spinoffs whose impetus could be discerned from the historical record, which included spinoffs that were started due to a disagreement in the parent firm about strategy or innovation, the failure or imminent failure of the parent firm (or its automobile business), or the desire of the parent firm to market a new car through a separate organization in order to preserve its image. The distinctive quality of these spinoffs is that they generally built directly on the expertise of their parents while at the same time differentiated themselves from their parents.[20] It was expected that the spinoffs that built in discernible ways on the expertise of their parent would have lower hazards, ceteris paribus.[21]

The coefficient estimates of all of the added variables are negative, as predicted, with only the dummy for the spinoff's secondary parent not significant. Moreover, the coefficient estimate of the Detroit-area spinoff variable is small and insignificant. Thus, crude controls for the heritage of the spinoffs largely explain the superior performance of the Detroit-area firms, suggesting further that there were no particular advantages to locating in the Detroit area. The coefficient estimate of the spinoff dummy is also small and insignificant, indicating that the superior performance of spinoffs was restricted to those with a distinctive heritage and that built on the expertise of their parents.

The absence of a Detroit-area effect is probed further by estimating Model 4, which drops the spinoff and Detroit-area spinoff dummies and adds two covariates to $\underline{z}$

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[19] When the two included dummies were broadened to encompass parents who were the number two producer, their explanatory power declined considerably. The production leaders of the industry, in particular Olds and Ford, were the first to mass produce automobiles and apparently provided novel challenges to their employees. Indeed, Ransom Olds, the founder of Olds Motor Works, was known as the "Schoolmaster of Motordom" (Doolittle, [1916, p. 44]).

[20] Descriptions of the origins of the other spinoffs suggest they were not so closely linked to their parents, although no doubt the brevity of the historical record for some obscured their connection to their parents.

[21] Note that many of these spinoffs, especially the ones whose parents' failure was imminent, did not produce very long. Not surprisingly, their parents did not generally produce long either. All that is predicted is that after controlling for the years of production of their parent and the other variables in the model, these firms survived longer, ceteris paribus. Efforts to break down the 1-0 dummy according to the particular motivation of the spinoffs were not productive.

that interact the dummy for location in the Detroit area with the years of production of the spinoff's parent and the dummy for the spinoff having a discernible reason for its formation.[22] This makes it possible to test if the spinoff background variables had similar effects for Detroit-area and non-Detroit-area spinoffs. The estimates of the interacted variables are small and insignificant, while the coefficient estimates of the main variables continue to be negative and significant. This implies that background similarly affected the hazard of spinoffs everywhere. To gauge the effects of all the background variables, one last model, Model 5, was estimated without the two interactive variables added to Model 4. The coefficient estimates of all four variables for the backgrounds of the spinoffs are negative and significant, along with nearly all the other background variables, confirming further the importance of pre-entry experience for firm performance.

B. Firm Fertility

The other key prediction of the theoretical model, which lies at the heart of its explanation for the concentration of the industry around Detroit, is that better-performing firms spawn more spinoffs (hypothesis 4d in Table 1). It was shown earlier that Olds, Buick/General Motors, Cadillac, and Ford, which were all located in the Detroit area, had the most spinoffs among all firms and that the Detroit area was characterized by a disproportionate number of spinoff entrants. A host of factors other than better performance, such as the Detroit-area firms producing longer, could account for their greater number of spinoffs. To test this, an ordered logit model was estimated of the annual rate of spinoffs of each firm in the industry. Nearly all the spinoffs entered between 1899 and 1924, and so the analysis is restricted to this period. Each firm's history is broken into annual intervals from the year before its date of entry[23] (or 1899 if it entered earlier) through 1924. The observations of all firms are pooled and an ordered logit is estimated of the factors influencing the annual probability of a firm having one, two, or three spinoffs.[24]

To control for all possible determinants of the spinoff rate, a specification similar to the one used by Klepper and Sleeper [2000] to analyze spinoffs in the laser industry is employed. The explanatory variables for each firm-year t include: a 1-0 dummy equal to 1 for firms that produced in year t; a 1-0 dummy equal to 1 for firms that did not produce

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[22] The two dummies for the spinoff's parent and secondary parent being the number one producer were not interacted with the Detroit-area dummy because all the spinoffs with primary or secondary parents that were the number one producer either entered in the Detroit area or, in the case of one spinoff, moved there after it entered.

[23] The firm's entry date is its initial year of commercial production in Smith [1968]. Some firms were organized before this date, and in two instances spinoffs entered in the year prior to the first year of commercial production of the parent firm. To accommodate this, the analysis was started in the year prior to each firm's initial year of commercial production.

[24] While 130 of the spinoffs occurred in years in which firms had only one spinoff, an ordered logit was used because there were six years in which firms had two spinoffs and one year in which one firm had three spinoffs.

in year t but had ceased producing less than five years earlier; the number of years of production through year t and the number of years of production squared for firms that produced in year t; the total number of years the firm produced autos;[25] a 1-0 dummy equal to 1 if the firm had been among the production leaders of the industry in year t or the preceding five years and a 1-0 dummy equal to 1 if the firm had been the number one or two producer in year t or the preceding five years;[26] a 1-0 dummy equal to 1 for firms that were acquired by another auto firm between year t-1 and t+2 and a comparable 1-0 dummy equal to 1 for firms acquired by nonauto firms between year t-1 and t+2, both of which were based on listings of ownership changes in Smith [1968]; a variable equal to the number of nonspinoff entrants divided by the number of firms averaged over years t-2, t-1, and t; and two 1-0 dummies for firms located in the Detroit area, with the first dummy equal to 1 for firms located in the Detroit area in year t and the second equal to 1 for firms located in the Detroit area in year t for years greater than 1916.

The firm spinoff rate is allowed to vary according to the firm's history of production under the expectation that firms no longer producing, especially ones that had not produced for over five years, would have lower spinoff rates.[27] The number of years of production through year t (for producers in year t) was included to allow more experienced firms to have more knowledge for employees to draw upon, increasing the spinoff rate. It was entered quadratically to allow for the possibility of a firm's knowledge becoming more embodied in the production process as it aged and grew, with such knowledge possibly more difficult for employees to access, thus lowering the spinoff rate. The years of production and production leadership variables were included to test whether a firm's performance affected its spinoff rate, as the theoretical model presumes. The acquisition variables were included to allow for the possibility of acquisitions causing changes in firm strategies, which could provide greater opportunities for spinoffs to exploit expertise gleaned from their parent. The nonspinoff entry variable was included to allow the spinoff rate to vary according to the attractiveness of entry generally.[28] Last, the Detroit-area dummies were included to test whether the Detroit-area firms had higher spinoff rates even after controlling for their greater success. A separate dummy for years after 1916 was included to test whether the spinoff rate of Detroit-area firms was lower in

[25] As in the hazard analysis, acquired firms that played an important role in their acquirer were assigned the same number of years of production as their acquirer. In addition to Olds, Cadillac, Chevrolet, Overman, and Rauch & Lang, the firms affected included Oakland, Edwards, Lincoln, Dodge, and Motorcar.

[26] In contrast to the hazard analysis, including the number two producer increased the explanatory power of this variable. This largely reflects the comparable spinoff rates of Cadillac and Buick/General Motors to Olds and Ford.

[27] If employees started firms after the exit of their parents, which occurred in some cases, then firms would have spinoffs after they ceased producing, but this was not expected to be the norm.

[28] This was alternatively controlled using year dummies, which had little effect on the estimates

later years, with 1916 chosen as the cutoff based on the fall in the entry of all firms in the Detroit area after 1916.

The estimates of the coefficients of the variables and three constant terms quantifying the thresholds for one, two, and three spinoffs are reported in Table 5.[29] The estimates largely conform with expectations. The probability of a spinoff is significantly greater in years firms were producing. It is also significantly greater for firms that had ceased producing within the last five years (relative to firms that had ceased producing over five years ago, the omitted reference category). For producers, the probability of a spinoff increases significantly through approximately age 14, after which it declines significantly. Klepper and Sleeper [2000] found a similar relationship for laser spinoffs. The probability of a spinoff is significantly greater around times that firms were acquired by either auto or nonauto firms. It is also significantly greater in years with a higher nonspinoff entry rate. In terms of the critical variables for the theory, the probability of a spinoff each year is significantly greater for firms that produced longer. It is also significantly greater for firms that were among the production leaders in the contemporaneous or prior five years, and significantly greater still for firms that were the number one or two producer in this same time period. Thus, consistent with hypothesis 4d, firms that performed better had higher annual spinoff rates.

The coefficient estimate for the Detroit-area dummy is positive and significant. It is almost completely offset by the negative coefficient estimate for the Detroit-area dummy after 1916, which is also significant. Thus, after 1916 the Detroit-area firms were not especially fertile, but before that Detroit-area firms spawned more spinoffs than expected based on their performance. The effect is quite large—the coefficient estimate of the Detroit-area dummy implies that through 1916 Detroit-area firms were about three times as likely to spawn one or more spinoffs than firms of comparable performance located elsewhere.[30] Thus, a substantial part of the greater fertility of the Detroit-area firms appears to have been attributable to circumstances peculiar to the Detroit area. In con-

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[29] The model was also estimated as an ordinary logit, and the coefficient estimates were very similar. The ordinary logit was useful because it could also be estimated with firm fixed effects using the approach developed by Chamberlain [1980]. In this approach, the likelihood of each observation for each firm i is expressed conditional on the total number of spinoffs of firm i. The procedure requires dropping all the firms from the sample with no spinoffs and dropping the variable(s) that do not vary over the observations for a firm (i.e., the total years of production). A Hausman test comparing the Chamberlain coefficient estimates with those based on ordinary logit estimation on the reduced sample and variable set (cf. Greene [1993, p.657]) could not reject the null hypothesis of the firm fixed effects equaling zero.

[30] The coefficient estimates can be interpreted in the conventional way as the derivative of the log odds ratio with respect to the explanatory variables, where the log odds ratio is the log of the probability of one or more spinoffs divided by one minus this probability (cf. Cox and Snell [1989, p. 159]). Thus, exp(1.2079) = 3.346 quantifies how much greater the odds ratio is for Detroit-area firms than firms located elsewhere. Since the annual probability of firms spawning one or more spinoffs is quite low, the denominator in the odds ratio is close to one, implying that the annual probability of a spinoff through 1916 was around three times greater for Detroit-area firms than firms located elsewhere.

trast, the hazard analysis suggested that the greater longevity of the Detroit-area firms, and in particular the Detroit-area spinoffs, was not primarily due to circumstances peculiar to the Detroit area but could largely be traced back to four very successful early entrants.

VII. Discussion

The findings are first summarized, and then the implications of the findings are discussed.

Initially a large number of firms entered the automobile industry and the number of producers peaked at 272 in 1909. Subsequently entry fell sharply and became negligible by the 1920s and the industry experienced a sharp and prolonged shakeout. Diversifying firms in related industries and firms founded by the heads of such firms tended to enter early, but few entered in the Detroit area. Consequently, there was little initial entry in the Detroit area, and in total the Detroit area only attracted 15% of all the entrants to the industry. But fueled by spinoffs, which accounted for a disproportionate share of entrants in the Detroit area, the percentage of producers in the Detroit area rose over time. By the late 1910s most of the leading makes of automobiles were produced by Detroit-area firms, and Detroit was home to the three firms that by the 1930s produced over 80% of the industry's output.

The performance of firms in terms of the hazard of exit was strongly related to their time of entry and the firms' pre-entry backgrounds. Entry cohorts had similar hazards at young ages but at older ages their hazards diverged sharply according to their time of entry. Firms with experience in related industries and firms founded by heads of firms in these industries had lower hazards at every age, particularly if the industries in which they participated were more closely related to automobiles. Better-performing firms and firms located in the Detroit area had higher spinoff rates, and better-performing firms had spinoffs with lower hazards at every age. Spinoffs did not venture far from their parents, and many of the Detroit-area spinoffs, especially the most successful ones, could be traced back to Olds, Buick/General Motors, Cadillac, and Ford, four of the most successful early entrants into the industry that all happened to locate in the Detroit area.

These patterns are revealing about the forces that shaped the evolution of the industry. Consider first the findings about how firm hazards were related to the time of entry. It appears that early entrants had substantial competitive advantages that surfaced as the industry evolved. A few later firms, such as Chrysler, that built on the efforts of earlier entrants were successful, but later entrants that started from scratch were rarely able to compete very long in the industry.[31] Strong advantages to early entry would help explain the eventual falloff in the rate of entry that occurred in the industry. With entry

[31] In the analysis, firms like Chrysler are not counted as entrants but as continuations of other firms and thus do not influence the hazard rates of the later entry cohorts.

eventually becoming negligible, a shakeout in the number of producers was inevitable, with earlier entrants taking over an increasing share of the industry's output. Once the window of opportunity for entry closed, there was also little chance of entry overturning the established geographic distribution of activity around Detroit that had already arisen.

The fact that entry cohort hazard rates diverged with age suggests that earlier entrants possessed a competitive advantage that did not dissipate as they and the other firms in the industry grew over time. Such a pattern suggests that shakeouts were not triggered by particular technological developments, whose effects would be expected to dissipate over time, but were part of a broader process of industry evolution (cf. Klepper and Simons [2001]). Not many factors could account for the persistently lower hazards of earlier entrants. Production scale economies eventually were prominent in the industry, but competitive advantages associated with production scale economies might be expected to diminish in importance as firms grew. Similar reasoning applies to learning by doing. The most obvious candidate driving the persistent advantage of the earlier entrants were the dramatic technological advances achieved in the industry, especially in the production process. Such advances required costly efforts, and the larger the firm then the greater the output over which it could amortize these efforts. Consistent with the model, Klepper and Simons [1997, 2001] found that early automobile entrants were in the vanguard of innovation, particularly process innovation, and innovators had markedly lower hazards.[32]

The importance of technological change provides a way of explaining the long-term effects of pre-entry experience on firm hazards, linking the productivity of firms' R&D efforts to their pre-entry experience (cf. Holbrook, Cohen, Hounshell, and Klepper [2000]). The similar hazards of experienced firms and experienced entrepreneurs and the low hazards of spinoffs, especially ones descended from more successful firms, suggests that in autos key capabilities resided as much in people as organizations. Olds, Buick/General Motors, Cadillac, and Ford exemplify this. Each had a famous leader with distinctive pre-entry experience in engines, carriages, or autos. In turn, these firms proved to be fertile training grounds for many other great auto men who started nearly all the other firms in the Detroit area that made it into the ranks of the industry leaders. Indeed, two of the leading historians of the auto industry attributed its concentration around Detroit to the preponderance of great men located there (Rae [1980], May [1977]). They did not explain, though, why so many great men were located in the Detroit area. The

[32] Klepper [2002a] found that other industries that experienced extreme shakeouts, including tires, televisions, and penicillin, had similar firm survival patterns to automobiles, and these industries were also characterized by rapid rates of technological advance in both their products and production processes. Moreover, detailed analyses of firm survival and innovation in both tires and televisions suggested that early entrants and firms with greater related pre-entry experience were in the vanguard of innovation, and this was key to their greater longevity and superior performance (Klepper and Simons [2000a, 2000b]).

theoretical model can't explain why four of the most successful early firms arose in the Detroit area, which was an unlikely place for this to occur given the paucity of early entrants around Detroit.[33] But given the chance occurrence of four such firms around Detroit, the theory can explain the subsequent concentration of great men around Detroit that propelled Detroit to become the capital of the U.S. automobile industry, attributing it to the birth and heredity process governing spinoffs.

The extraordinary success of many of the spinoffs in the Detroit area and the connection between the performance of spinoffs and their parents suggests that successful incumbent firms can be powerful incubators of significant later entrants. Indeed, the success of firms in the Detroit area was largely confined to the Detroit-area spinoffs. If agglomerations result from positive spillovers associated with R&D and/or input markets, as Alfred Marshall and others have conjectured, or from having producers and their suppliers locate close to each other and to buyers, as in Krugman et al.'s model, then the benefits of locating in the Detroit area should have been experienced by all types of firms. Moreover, it is not clear that there were any benefits from locating in the Detroit area. The success of the Detroit-area spinoffs can largely be explained by the superior performance of their parents and their greater proclivity to build on the expertise of their parents.

The theoretical model contains a number of elements that are needed to generate the extreme agglomeration of activity that characterized the auto industry. One is the ability of de novo firms founded by people with distinctive experience to compete with organizations diversifying from related industries. This does not occur in all industries. For example, the television industry evolved in a very similar way to autos (Klepper [2002a]), but the industry was dominated by firms diversifying from the radio industry. Consequently, the geographic distribution of activity did not concentrate in any one place, but largely reflected the geographic distribution of the radio producers. A second aspect of the model contributing to the agglomeration of activity is the advantage of early entrants associated with technological change. This eventually causes entry to dry up, which not only contributes to a shakeout of producers but also limits the extent to which agglomerations can be overturned once they occur. While many technologically progres-

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[33] It may have been partly due to Olds Motor Works, which influenced the other three firms. Olds was the first large-scale producer of automobiles, and it contracted on a large scale for a number of its major inputs. Henry Leland, the driving force behind Cadillac, first supplied engines and transmissions to Olds, and he used an improved version of the engine he supplied to Olds in the original Cadillac model. The Dodge Brothers also supplied engines to Olds. No doubt this experience influenced them to agree to supply engines and other major components to Ford Motor Co. when it entered, which was key to Ford's initial success. Buick was less directly influenced by Olds, but its original funding (on a very small scale) was provided by the Briscoe brothers, who had supplied radiators to Olds. While none of these firms was classified as a spinoff of Olds Motor Works, they were certainly influenced by Olds in ways that were similar to Olds' spinoffs.

sive industries eventually experience a drying up of entry and greater longevity of earlier entrants (cf. Klepper [2002a]), some, such as lasers, do not. Although spinoffs were also prominent in the laser industry, the industry has experienced a continual turnover of firms that seems to have limited its geographic concentration (Klepper and Sleeper [2000]). Last, in the model agglomeration depends on the chance location of a few successful firms in one narrow region. This is certainly a rare event. If all three conditions of the model are required to produce the kind of agglomeration that characterized autos, it would explain why such extreme agglomerations are rare (Ellison and Glaeser [1997]).[34]

The model implies that a region, including a nation, will not naturally develop a presence in a new industry unless it has firms in related industries that could successfully diversify into the new industry and subsequently spawn other entrants. It does not rule out, though, that a region could generate qualified entrants through a government-supported seeding process. The model is less informative about whether nations would find it beneficial to promote geographic agglomeration of evolving industries. There are no social advantages to agglomerations in the model. But judging from the experience of Silicon Valley, which appears to have been fueled by spinoffs in semiconductors (Brittain and Freeman [1986]) and other industries such as disk drives (Franco and Filson [2000]) and lasers (Klepper and Sleeper [2000]), agglomerations driven by spinoffs may well promote economic growth. Exactly how this occurs and whether in fact spinoffs are socially beneficial is an unresolved question (cf. Klepper and Sleeper [2000], Klepper [2001]). The rate of spinoffs was much higher in the Detroit area than expected based on the explanatory variables of the order logit model, suggesting that agglomerations may promote spinoffs, which would be socially beneficial if spinoffs are an important element of the growth process. If spinoffs are socially beneficial, then promoting spinoffs through such policies as restricting noncompete convenants and trade secrets may be warranted (cf. Hyde [2000], Klepper [2001], Stuart and Sorenson [2001]). Nations may even want to take steps to reduce any stigma associated with employees leaving to start their own firms and the inevitable failures that will result from more employee startups.

In conclusion, by appending a birth and heredity process to a model of industry evolution it was possible to explain the evolution of both the market structure and geographic distribution of activity in the automobile industry. Much remains to be explored about how firms acquire and exploit their capabilities, but the analysis of the automobile

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[34] Once agglomerations occur, though, the model predicts they will tend to be self-reinforcing, which could explain Sorenson and Audia's [2000] finding for the footwear industry that firms entered disproportionately in agglomerated areas even though firms in those areas had *shorter* lifetimes, ceteris paribus.

industry illustrates the kinds of insights that can be gained by studying the origins of entrants and the spinoff process.

Table 1: Hypotheses

1. Among all firms and each type of entrant, the hazards of early and late entrants cannot be ordered at young ages, but at older ages the early entry cohorts will have lower hazards and will become extinct later than the late entry cohorts.
2. Among contemporaneous entrants, experienced firms, experienced entrepreneurs, and spinoffs will have lower hazards at every age than inexperienced firms.
3. Among contemporaneous entrants, spinoffs from better-performing parents and experienced firms and experienced entrepreneurs with experience in industries more related to automobiles will have lower hazards at every age.
4. a. The number of spinoff entrants relative to the number of experienced firm and experienced entrepreneur entrants will steadily rise over time.
   b. The number of experienced firm, experienced entrepreneur, and spinoff entrants relative to the number of inexperienced firm entrants will eventually rise as the industry evolves.
   c. The performance of the parents of spinoff entrants will improve over time.
   d. Better-performing firms will spawn more spinoffs.
5 a. The spinoffs of Detroit-area firms will locate in the Detroit area and the spinoffs located in the Detroit area will have parents located in the Detroit area.
   b. The percentage of entrants that are spinoffs will be higher in the Detroit area than elsewhere.
   c. Parents of Detroit-area spinoffs will perform better than parents of spinoffs elsewhere.
   d. A few early Detroit-area entrants should rank high on the list of firms with the greatest number of spinoffs, and the most successful spinoffs in the Detroit area should be related, either directly or through their spinoffs, to these firms.
   e. Spinoffs located in the Detroit area will have lower hazards at every age than spinoffs located elsewhere.
   f. Inexperienced firms located in the Detroit area will not have lower hazards at every age than inexperienced firms located elsewhere.

Table 2: Entrants by Background and Time of Entry

Period	Total	# of Experi-enced Firms (EF)	# of Experi-enced Entrepreneurs (EE)	# of Spinoffs (SP)	# of Inexperi-enced Firms (IF)	SP/ (EF+ EE)	(SP/ IF)	(EF+ EE)/ IF
1895-1904	219	46	45	16	112	.18	.14	.81
1905-1909	271	43	32	47	149	.63	.32	.50
1910-1966	235	31	31	82	91	1.32	.90	.68
Total	725	120	108	145	352	.64	.45	.70

Table 3: Firms with the Most Spinoffs

Firm	Number of Spinoffs	Number of Descendants	Number of Descendants Among Production Leaders	Year of Entry	Rank Among Production Leaders w/in 5 Years of Entry	Leader & Prior Background
Olds	7	13*	5	1901	#2 1901-02 #1 1903-05	Ransom Olds, head, engine firm
Buick/GM	7	9	2	1903	#9 1905 #8 1906 #2 1907	William Durant, head, carriage firm
Cadillac	4	5**	3**	1902	#3 1903 #2 1904-06	Henry Leland, head, engine firm
Ford	4	9	1	1903	#2 1903 #4 1904-05 #1 1906-07	Henry Ford, auto founder
Maxwell-Briscoe	4	5	0	1904	#8 1905 #5 1906 #4 1907-08	Jonathan Maxwell, auto employee & founder

* Includes Maxwell-Briscoe but not Maxwell-Briscoe's descendants

** Includes Ford but not Ford's descendants

Table 4: Coefficient Estimates of the Hazard Model
(Standard Errors in Parentheses)

Variable	Model 1	Model 2	Model 3	Model 4	Model 5
Constant	-1.5145*** (0.1046)	-1.5376*** (0.1046)	-1.5537*** (0.1036)	-1.5969*** (0.1009)	-1.5926*** (0.1003)
t	0.0601*** (0.0143)	0.0587*** (0.0141)	0.0581*** (0.0139)	0.0558*** (0.0136)	0.0569*** (0.0136)
Detroit	-0.2928** (0.1207)	0.0163 (0.1530)			
Exp. firms	-0.4146*** (0.1467)	-0.4098*** (0.1467)	-0.4112*** (0.1467)	-0.3872*** (0.1457)	-0.3914*** (0.1456)
Exp. entrep.	-0.5015*** (0.1524)	-0.5360*** (0.1532)	-0.5496*** (0.1528)	-0.5170*** (0.1514)	-0.5222*** (0.1512)
Spinoffs	-0.5639*** (0.1217)	-0.3917*** (0.1287)	-0.1410 (0.1588)		
C1	-0.1505 (0.1357)	-0.1522 (0.1350)	-0.1272 (0.1350)	-0.0971 (0.1342)	-0.0976 (0.1339)
C2	0.0332 (0.1291)	0.0152 (0.1291)	-0.0035 (0.1306)	0.0254 (0.1294)	0.0260 (0.1292)
C1*t	-0.0878*** (0.0162)	-0.0852*** (0.0160)	-0.0839*** (0.0159)	-0.0817*** (0.0157)	-0.0832*** (0.0156)
C2*t	-0.0490*** (0.0175)	-0.0413*** (0.0176)	-0.0306** (0.0179)	-0.0310** (0.0177)	-0.0316** (0.0176)
C,b,e firms	-0.4052** (0.1928)	-0.4145** (0.1928)	-0.4290** (0.1930)	-0.4172** (0.1927)	-0.4199** (0.1927)
C,b,e entrep.	-0.2408 (0.2023)	-0.2341 (0.2023)	-0.2273 (0.2023)	-0.2262 (0.2023)	-0.2260 (0.2022)
Det. spins		-0.7826*** (0.2590)	-0.2515 (0.2323)		
Yrs par.prod			-0.0086** (0.0048)	-0.0093** (0.0041)	-0.0121*** (0.0041)
Parent #1			-0.9541** (0.5482)	-0.6246 (0.6249)	-0.9183** (0.5288)
Sec.par #1			-0.5571 (0.4837)	-0.7759** (0.4716)	-0.7774** (0.4616)
Spin reason			-0.3413* (0.2190)	-0.4031** (0.2406)	-0.4982*** (0.1944)
Yrs prod*D				-0.0055 (0.0082)	
Sp. Reas*D				-0.0039 (0.0092)	
Log Likel.	-1872.18	-1867.58	-1858.82	-1859.62	-1860.08

*** significant at the .01 level (one-tailed)
** significant at the .05 level (one-tailed)
* significant at the .10 level (one-tailed)

Table 5: Coefficient Estimates of the Ordered Logit Model (Standard Errors in Parentheses)

Variable	Coefficient Estimate
Constant1	-6.6851 (.3615) ***
Constant2	-9.7128 (.5174)**
Constant3	-11.6736 (1.0608) ***
Dummy—producing	1.1763 (.4652)***
Dummy--≤5yrs.notprod.	1.3865 (.4131)***
Yrs. Prod. if producer	0.1772 (.0648)***
Yrs. Prod.^{2} if producer	-0.0065 (.0030)**
Yrs. survived	0.0133 (.0077)**
Production leader	0.7605 (.3343)**
#1 or #2 producer	0.6789 (.3951)**
Acquired by auto firm	0.9551 (.3440)***
Acquired by nonauto firm	0.8468 (.2616)***
Nonspin. entry rate	0.9258 (.5239)**
Detroit area	1.2079 (.2279)***
Detroit area after 1916	-1.1251 (.4008)***

*** significant at the .01 level (one-tailed)
** significant at the .05 level (one-tailed)
* significant at the .10 level (one-tailed)

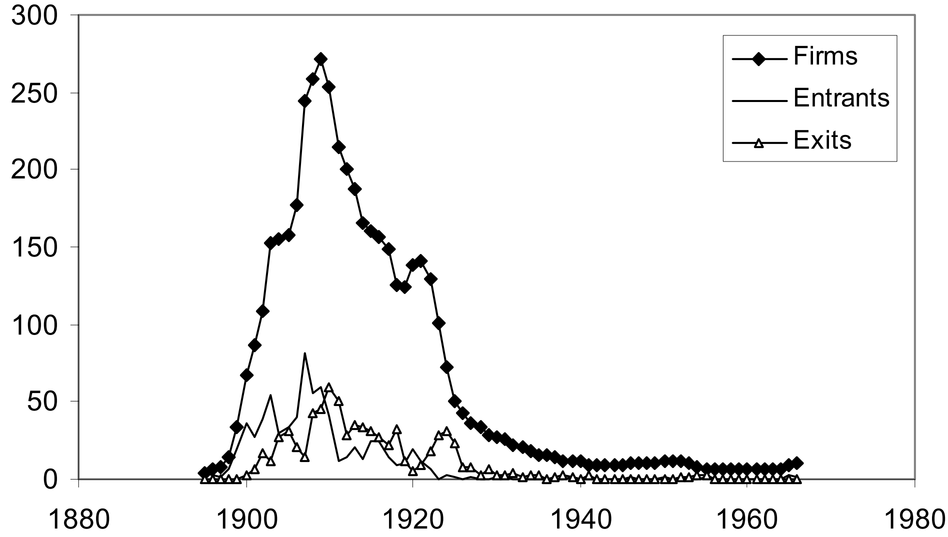

Figure 1: Entry, Exit, and Number of Firms

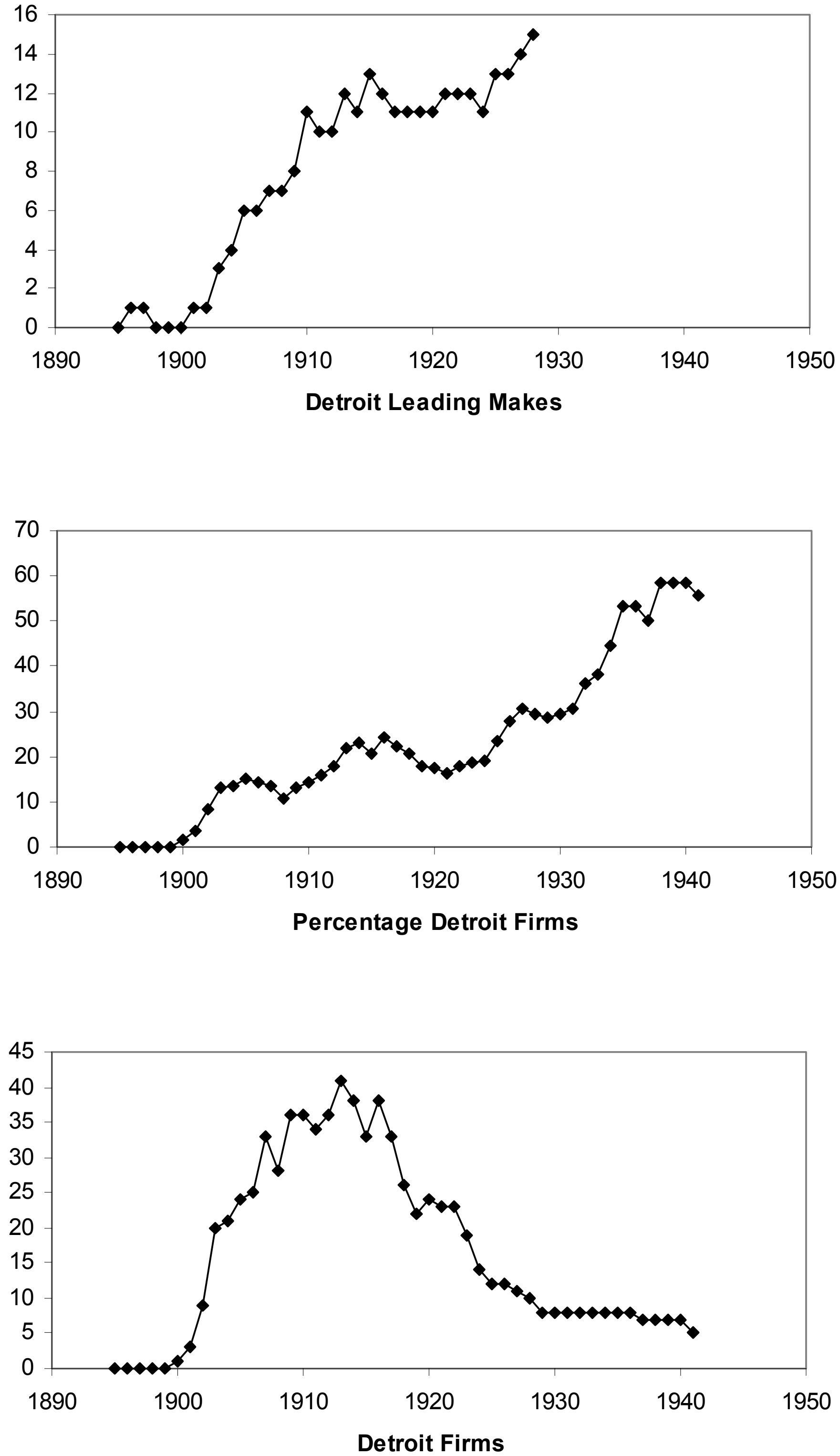

Figure 2: Location of Firms Around Detroit

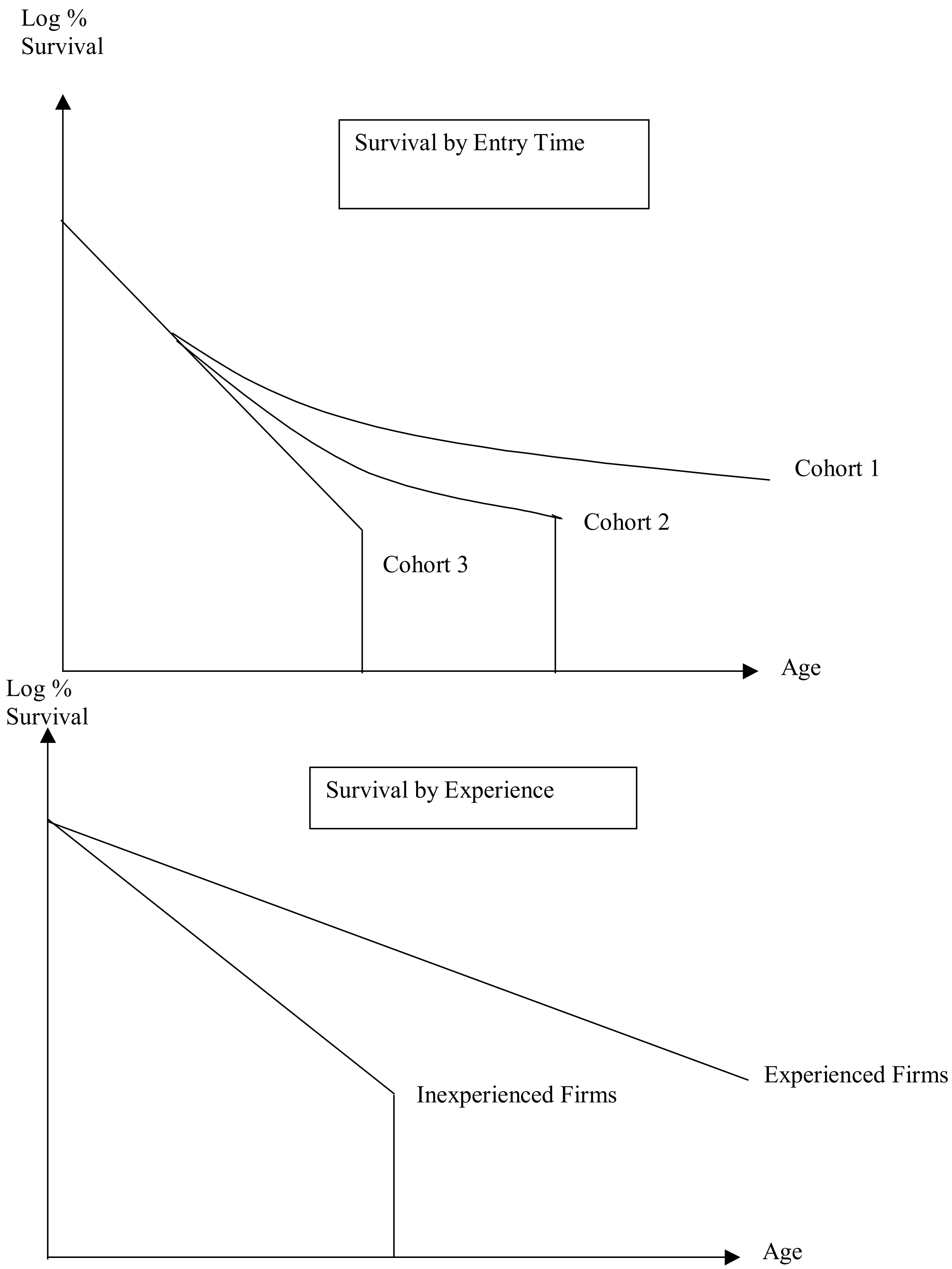

Figure 3: Survival Graphs

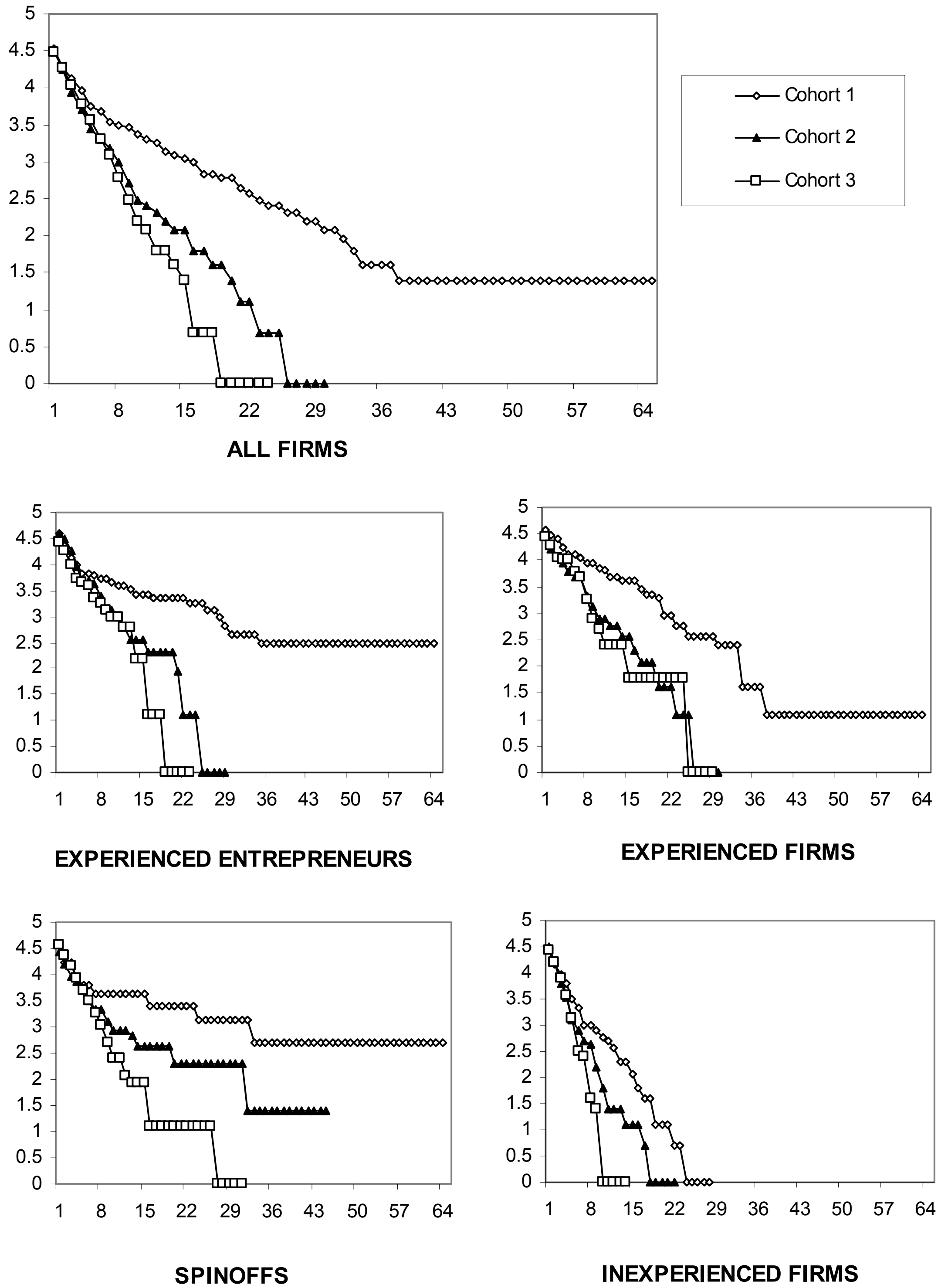

Figure 4: Survival Curves by Time of Entry

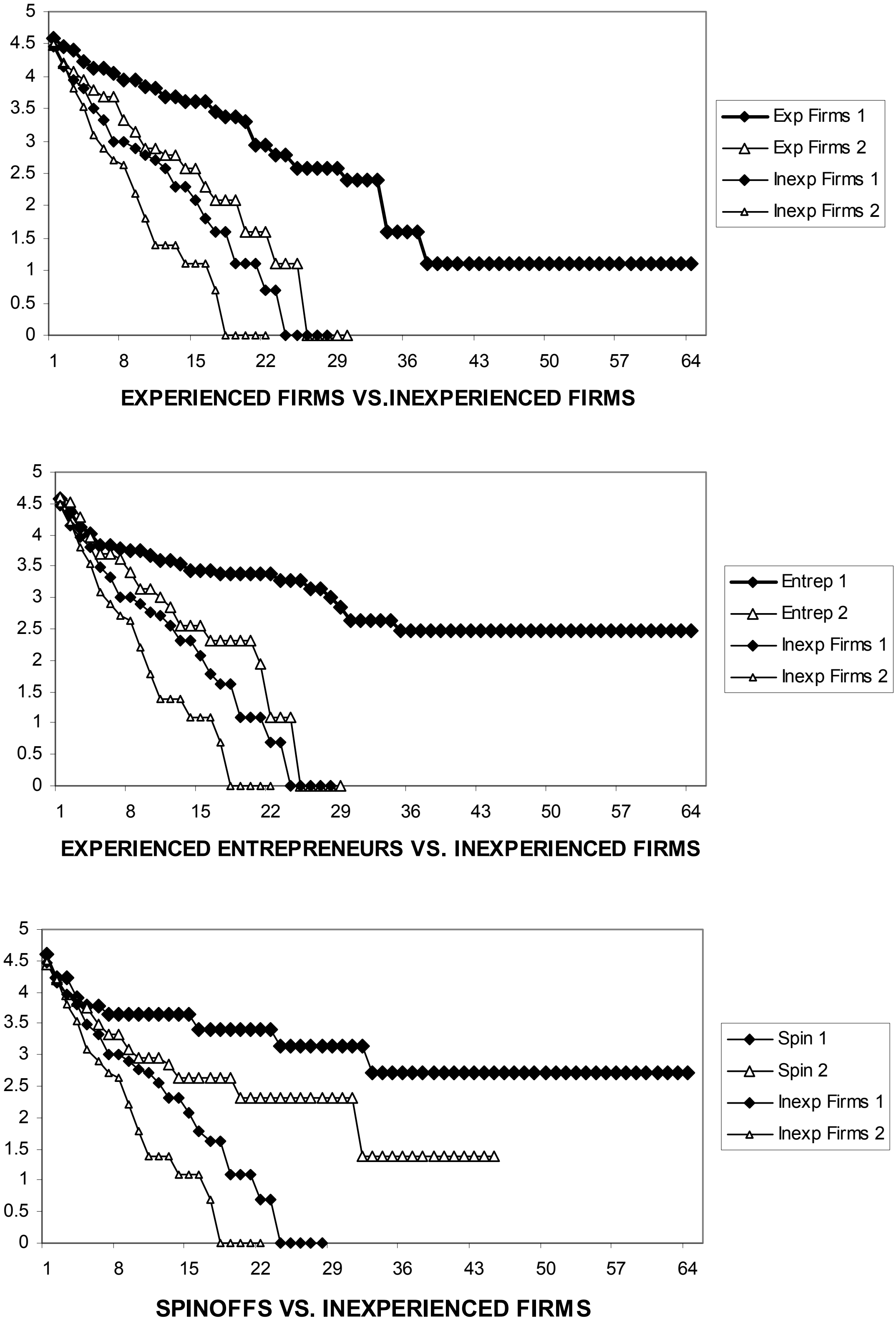

Figure 5: Survival Curves of Inexperienced Firms vs. the Other Three Groups of Firms

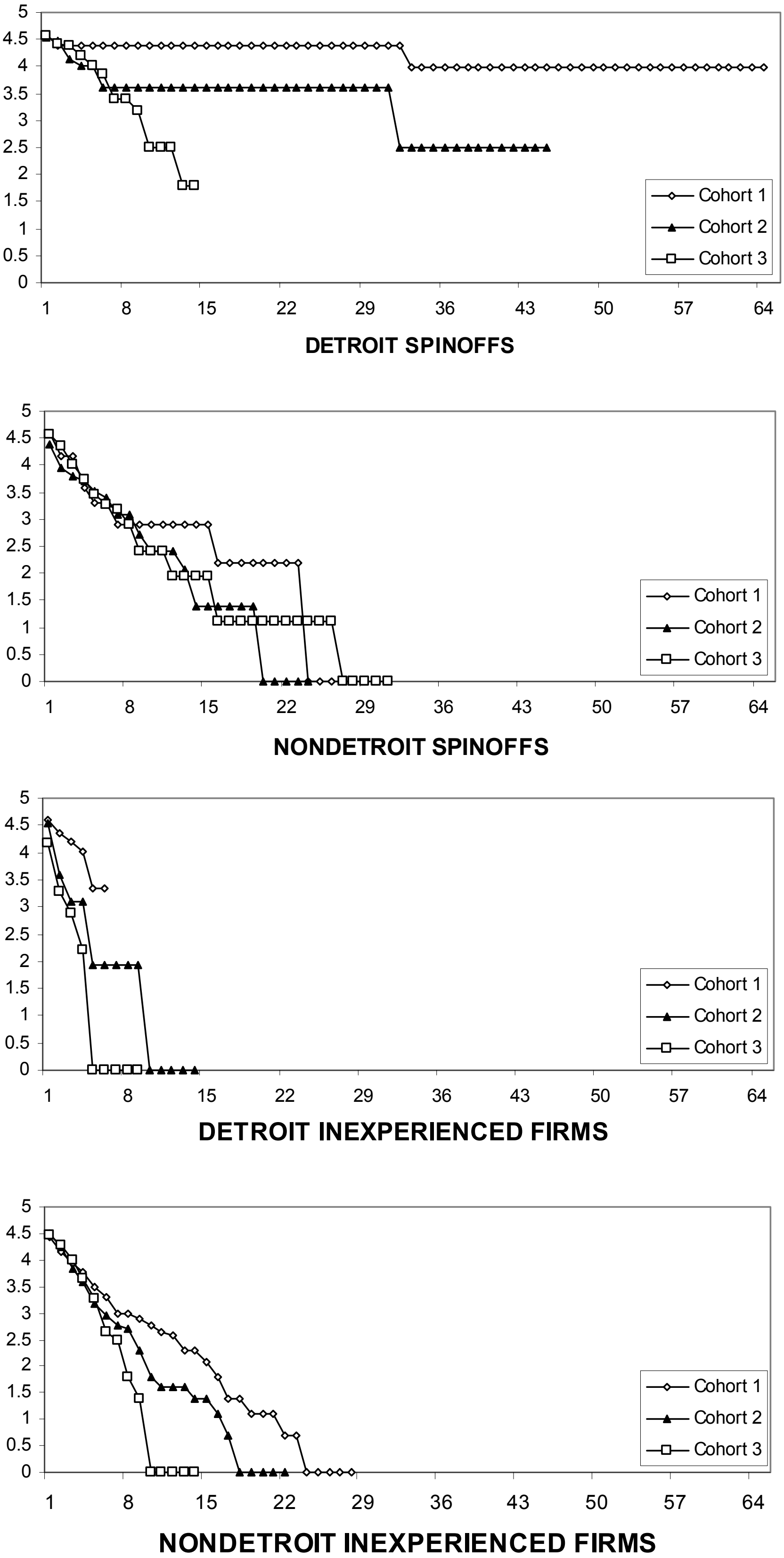

Figure 6: Survival Curves of Detroit and Non-Detroit Spinoffs and Inexperienced Firms

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